TESTING CABLES FOR CARRIER APPLICATION

CONTENTS

1. GENERAL

1.1 This section provides guidelines to REA borrowers and consulting engineers in testing cables for carrier application. Before the final decision is made to purchase and install carrier equipment, the cable facilities must be measured and the data analyzed to assure that the cables will support the equipment. Since the suitability of existing cables is usually a significant factor in the economic choice of carrier over physical plant reinforcement, cable testing should be done at an early stage in the planning.

1.2 The primary purpose of cable testing can be summarized:

1. To determine the condition of the cable.

2. To judge if the cable is suitable for carrier application (before making a large investment in carrier equipment).

3. To provide a sound foundation for reliable carrier operation.

1.3 Secondary benefits of cable testing are:

1. To verify that repeaters are at proper location and subscriber terminals are within specified limits.

2. Data serves as a benchmark reference for future testing. Marginal, but acceptable, cable sections can be noted for future reference.

1.4 Reliable, troublefree service depends on good shielded cable facilites. The use of RDW, open wire or other unshielded facilities are not recommended for carrier system transmission. The use of unshielded facilities for station carrier application should be considered only as a temporary solution to an urgent service requirement; and considered only where there are definite plans to upgrade these facilities in the near future.

2. RECOMMENDED TESTING

2.1 The main purpose of testing cables is to determine that they are free of moisture and that the shields are continuous. A secondary purpose is to verify that the cable gauges and lengths are correct as shown on the maps and records so that equipment can be properly applied. To support a large quantity of carrier equipment without transmission problems and excessive maintenance, good stable electrical transmission characteristics are necessary.

The tests outlined in this section are primarily for existing exchange cable plant being converted from voice subscriber loops to station carrier or PCM subscriber carrier service. As the tests apply, they can be used for PCM and analog trunk carrier application also. Cable acceptance tests for new cable are outlined in PC-4, REA Standard for Acceptance Tests and Measurements of Telephone Plant.

2.2 In an effort to keep testing to a minimum, three basic tests are proposed to determine if the cable is suitable for carrier. They are:

1. Insulation Resistance
2. Shield Continuity
3. Insertion Loss

These tests are covered in paragraphs 3, 4 and 5, and are <u>indicators</u> of the cable condition. Supplemental testing may be required if questions are raised by the measurement data. Before PCM carrier is applied to small non-screen exchange cables, it may be necessary to make near-end crosstalk loss measurements (see paragraph 8.4).

2.3 The quantity of testing required to determine cable suitability depends on several factors. Measurements should be made on some minimum number of pairs in each cable section. If the facilities are existing air core cables, more extensive testing will be required than for new, filled cables. Also, use trouble records as a guide. If the cables have been troublesome (open pairs for example) for voice frequency circuits, they are likely to be more troublesome as carrier circuits. If they have provided good voice frequency service and test good on a voice frequency basis, they are more likely to support carrier service.

2.4 Most cable transmission data is shown at 68°F. If the cable temperature is within 50 to 90°F, temperature corrections are small. If the cables are measured in mid-winter or mid-summer, corrections to measured data will be necessary. Based on periodic tests on small size cables, capacitance, conductance and carrier frequency insertion loss may exhibit large changes from mid-summer to mid-winter that cannot be accounted for by temperature alone. If the cables contain moisture (not water), the effect may not be apparent if the cable temperature is below 32°F. It is recommended that cables be tested for suitability during the spring, summer or fall if they are subject to freezing temperature during the winter.

3. INSULATION RESISTANCE

3.1 Measure the dc insulation resistance (leakage) of a large number of cable pairs at the central office mainframe as shown in Figure 1. Measure from tip to ring, tip to ground, and ring to ground. All non test pairs should be grounded if not in service; assigned pairs are effectively grounded through the central office line relays. Record all data.

3.2 A sensitive insulation resistance test set should be used for these tests. A wire chief's test set is not adequate since it is difficult to measure values of more than one megohm.

3.3 It would be beneficial to again measure insulation resistance in repeater sections as pairs are measured for insertion loss. This would especially be beneficial on those pairs showing "acceptable" but marginal values of insulation resistance.

4. SHIELD CONTINUITY

4.1 Electronic system protection considerations, high 60 hertz currents in cable pairs, voice frequency noise and carrier system noise considerations are all believed to go hand-in-hand. Continuous cable shields are necessary to minimize these problems, regardless of the frequencies transmitted through these cables.

4.2 To assure good continuity, there are two areas of concern. This is shield bonding at an accessible splice (i.e., pedestal housing) and continuity between accessible splices. This discussion is based on buried cable. Aerial cable bonding connections can be readily measured; but it is

much more difficult to determine if aerial cable shields are continuous between splices. Measurements of 60 hertz current in the cable pairs of operational carrier systems can be useful. Also, 60 hertz voltage to ground of cable pairs measured in repeater sections supplement shield continuity tests (see paragraph 7.21).

4.3 At each pedestal location, inspect the shield bonds and connection to the bonding lug. A shield continuity tester should be used to measure shield bonding at each pedestal.

4.4 To measure shield continuity between pedestals, use a wheatstone bridge as shown in Figure 2. Record all measured shield resistance values.

4.41 It is usually faster and more convenient to measure the shield resistance over distances greater than adjacent pedestals. This can be done if the following precautions are taken. Limit the distance between measurement points to about one mile intervals (load coil locations or T carrier repeater locations). Make sure the grounds and branch cable shields are removed from the cable shield under test at each intermediate pedestal location.

4.42 After the shield continuity measurements are completed, reconnect the bonds and grounds at each pedestal location. Repair shield bonds and tighten bonding lugs as necessary. Bonding problems within a pedestal are correctable (repairable). Locating and repairing broken shields between pedestals is more difficult, but must be done before carrier is applied.

5. INSERTION LOSS

5.1 Measure the cable insertion loss from 20 kilohertz to the highest frequency of the proposed carrier equipment at 40 kilohertz intervals. Select three or more pairs in each cable repeater section. These selected cable pairs should generally be the same pairs intended for carrier use. However, if the cable is existing air core cable, at least some of the pairs selected for testing should be along the outside layer of the cable. The outside layer pairs are usually more affected by moisture in the cable core.

5.2 Measure the cable in repeater section lengths. Measure the entire route from the central office to the most distant subscriber terminal location; or to the distant central office location in the case of trunk carrier. The measurement procedure is shown in Figure 3.

6. CAPACITANCE MEASUREMENTS

6.1 Mutual capacitance measurements are another guide to cable suitability. For capacitance measurements to be the most effective, they must be made in short lengths, not to exceed one voice frequency loading section (4500 or 6000 feet). Because of this, capacitance measurements are

usually made only to localize problems after loss measurements raise questions. Measuring loss on short lengths of cable can lead to large percentage errors. Capacitance measurements offer a measurement refinement on these short cable lengths.

6.2 Measure 1000 hertz mutual capacitance and dissipation. (Refer to TE&CM Section 435, Cable Capacitance Measurements, for more details.) Record the capacitance and dissipation for each pair measured along with other necessary information such as size, gauge, cable temperature, etc. It is unnecessary to correct the measured capacitance on short lengths of cable (up to 6000 feet). Mutual conductance can be found from series mode bridge measurement data by:

$$G = \omega^2 C^2 \left[\frac{D}{\omega C_s} - \frac{R}{3} \right]$$

where:

G = "true" conductance in mhos

ω = 6283

C = "true" capacitance (or corrected for length if necessary) in farads

D = measured dissipation ratio

C_s = measured capacitance, series mode, in farads

R = measured dc loop resistance (or estimated very closely) in ohms

7. EVALUATION OF DATA

7.1 Insulation Resistance: The primary purpose of insulation resistance measurements is to determine if the cable is basically suitable for carrier system application. A secondary purpose is to determine that individual cable pairs assigned for carrier application are free of defects. A more rigid set of requirements should be used for establishing acceptable limits on those pairs assigned for carrier, than to determine overall suitability of a cable route.

7.11 It is desirable that most of the pairs in a cable meet the 500 megohm miles minimum requirement established in PC-4. To avoid calculations, a value of 50 megohms minimum is established to represent a typical 10 mile length. If a larger value is established, minor leakage at

terminal and arrestor locations could lead to unnecessary concern. Most pairs of each cable route measured should be 50 megohms or greater. No pair should measure less than 10 megohms. (Carrier systems should be assigned only to those pairs measuring 50 megohms or greater.)

7.12 If many cable pairs measure less than 50 megohms, determine the cause of the low values. If they are caused by uninsulated terminals, station arrestors or connections in accessible housings, the problem can be corrected. If the low insulation resistance values are due to the cable plant, correction may be more difficult. But the cable must be corrected before carrier is applied. This may require the replacement of some cable sections or the repair of buried splices. Low insulation resistance often indicates pinholes and moisture. Pinholes and moisture generally add up to cable and carrier maintenance problems. Initially, these problems may be noticed as noise or intermittent carrier operation. Eventually, cable pairs will become open.

7.13 The value of insulation resistance may change from wet days to dry days due to leakage at accessible locations. The high leakage might be due to protector assemblies, terminal blocks or damaged wire insulation inside pedestal housings. This can usually be corrected; and should be corrected before applying carrier.

7.2 Shield Continuity: Compare the measured shield resistance to the estimated values shown in Table 1. The shield resistance of most cables is less than one ohm per kilofoot, or 5 ohms per mile. If measurement sections are limited to about one mile maximum, it is possible to detect shield breaks of 2 ohms resistance or less. Shield breaks of 4 ohms or more should easily be detected. In areas of high ground resistance and high lightning incidence, shield continuity is very important for reliable carrier operation.

7.21 Some station carrier equipment manufacturers recommend measuring the 60 hertz voltage to ground of each repeater section. This technique is shown in Figure 4. If the voltage to ground (across the 300 ohm resistor) exceeds 20 volts, additional 60 hertz drainage may be required for proper operation. Excessive 60 hertz current affects the carrier line powering and introduces noise into the carrier system. If the voltage exceeds 20 volts, adequate cable shielding may be in question. The high 60 hertz currents, voice and carrier noise considerations and carrier protection considerations are believed to go hand-in-hand. Even with continuous cable shields, heavy duty gas tube protection may be required to reduce excessive carrier failures on those routes where high values of 60 hertz current are measured.

7.3 Station Carrier: The measured and calculated insertion loss of cable sections should be within 10 percent after correcting for temperature. Refer to Table 1 for cable attenuation data and temperature corrections. If the measured attenuation is within 10 percent and the insulation resistance and shield continuity values are normal, the cable should be suitable for station carrier application.

7.31 Can station carrier be applied to cables measuring more than 10 percent high in loss? Questionable cables increase the risk of carrier maintenance problems. If the main cable route (up to the last repeater) tests good and the insulation resistance and shield continuity tests good, some additional loss might be allowed for end facilities so long as carrier system limits are not exceeded. If the measured loss of these end facilities is more than 20 percent higher than the calculated loss, carrier application is not recommended.

7.32 That is not to say that station carrier will not "work" on these cables. Under a very loose definition of "work", station carrier has "worked" over cables where the loss was 50 to 80 percent above normal. But the loss of moist cable can vary widely from summer to winter. Carrier systems can become noisy and intermittent. The risk of poor subscriber service outweighs the benefit in delaying the replacement or restoration of moist cable (see paragraph 9.2). Such a practice usually is only stalling what must be done anyway.

7.33 The measured loss of cable sections might be slightly high and the cable core not contain any significant quantity of moisture. This can occur on short measurement lengths, where measurement error could result in a large <u>percentage</u> of a small measured loss. Also the measured cable could have been manufactured to a higher capacitance than 0.083 microfarads per mile. Capacitance measurements offer some refinement in determining if moisture exists in the cable core, and to what degree.

7.34 Capacitance measurements at 1000 hertz are outlined in paragraph 6. Cable is questionable if capacitance has increased by more than 10 percent over normal, and if conductance is greater than 10 micromhos per mile (corrected for length). Consider the cable unsuitable if capacitance is more than 20 percent high and conductance exceeds 20 micromhos per mile. Judgment must be used. Short sections of questionable cable might be used beyond the last repeater, but not in the main part of the cable.

7.35 For extended systems (over 3 repeaters), the electrical transmission characteristics of cable may have to be better than the limits recommended above.

7.4 <u>Analog Carrier</u>: As a general rule, cable requirements for other analog carrier systems are similar to station carrier requirements. For N type carrier, compare the measured and calculated loss up to 260 kilohertz. If the loss (corrected for temperature) is within 10 percent and the insulation resistance and shield resistance are normal, the cable is probably suitable for N carrier application. Higher frequency carrier systems require better cables; more care may be required in selecting cables for these high frequency carrier systems. Generally these systems are designed so that **near end** cable crosstalk is not a consideration. However, far end cable crosstalk could become a limiting factor.

7.5 PCM Carrier: Good cables are more important for higher frequency carrier systems. PCM carrier depends on good cable stability. Moisture in the cable core can cause additional line loss, poorer crosstalk, and reflection of high frequency pulses. Filled cables with separated cores (screened) are preferred; but are often not available (existing cable) where needed for growth with PCM carrier. This discussion refers to the T1 type of PCM carrier.

7.51 The cable testing requirements for PCM carrier application are not as simple and straightforward as for lower frequency analog systems. The primary concern expressed here is to determine that the cable core is essentially moisture free.

7.52 The measurement of insulation resistance, shield continuity and insertion loss should reasonably indicate the condition of the cable. Insertion loss should be measured at enough frequencies to assure that the measured loss and the slope of the loss is normal. After correcting for temperature, the calculated and measured loss should be within 10 percent. If so, the cable is probably suitable for PCM carrier application.

7.53 Capacitance measurements can be used to supplement insertion loss measurements. These are outlined in paragraph 6. Cable is questionable if the capacitance has increased by more than 10 percent over normal, and if the conductance is greater than 10 micromhos per mile.

7.54 The above recommendations are a guide to cable suitability for PCM carrier. They are not a guarantee of cable suitability. The purpose of the testing proposed here is to be reasonably sure that the cable is basically moisture free and stable. There are also application considerations and restrictions that are beyond the scope of this discussion on testing. Cable near end crosstalk loss is one of these (see paragraph 8.4).

7.55 Other testing techniques for PCM carrier include the measurement of loss and error margin using random bipolar pulses, time domain reflectometry (TDM) or "radar" techniques, near end crosstalk loss at 772 kHz and others. Some of these techniques are discussed in paragraph 8, and can be used to supplement (or in lieu of) testing recommended above.

8. SUPPLEMENTAL PCM TESTING

8.1 As discussed in paragraph 7.55, supplemental testing of cables for PCM carrier application may be necessary. This discussion will describe some of those techniques. No attempt will be made to give guidelines as to acceptable limits of values. These limits are usually established based on a specific piece of test equipment. Refer to the test equipment manuals or other practices for these limits.

8.2 Loss and Degradation: A test set such as the Lenkurt 91100, Sierra 413A, or equivalent, can be used to measure the cable section loss and degradation. Two tests sets are required, one at each end of a cable section. The test set transmits a pseudo-random pulse pattern at a 1.544 megabit rate. The receiver (at the distant end) measures the cable pair loss at 772 kHz (equivalent). In addition, the receiver tests the immunity of the signal to crosstalk. The set allows the operator to inject increasing amounts of noise until errors begin to occur. The noise level is recorded, either in terms of dB or D-factor (degradation). If the results of this test and the loss test are within limits, the pairs should be suitable for T1 carrier. This test should be made on each pair as carrier systems are added to assure that crosstalk from existing systems is within limits.

8.3 Radar Test Set: Time domain reflectometry (TDM) or "radar" techniques can be used to "look" at each cable section. Water, loading coils, bridge taps, build-out capacitors and other discontinuities to PCM pulses can be found using this technique. The radar set transmits pulses into the cable pair. Discontinuities are viewed on an oscilloscope screen. This is more of a troubleshooting tool since the results are qualitative (oscilloscope trace patterns) and not quantitative.

8.4 Crosstalk Loss: While near end crosstalk loss (NEXT) is a cable suitability factor, it is more of an application consideration. A cable may be generally suitable for PCM carrier, but may present application limitations due to NEXT. NEXT measurements at 772 kHz are desirable on all small non-screen cables, especially air core cables. But NEXT measurements are difficult and time consuming to make on installed cables. Screened cables are designed to eliminate NEXT considerations and measurements.

8.41 NEXT measurements may be necessary to select transmit and receive pairs in small cables. NEXT measurements may also be necessary to determine the maximum number of systems and repeater spacing in cables.

NEXT must be measured between each transmit to receive cable pair combination proposed for T carrier systems (ultimate number of systems). (Some telephone operating company practices recommend the selection of random pairs for the NEXT measurement, and computing the mean minus one standard deviation (M-S) NEXT at 772 kHz.)

8.42 Near end crosstalk loss (NEXT) measurements are shown in TE&CM Section 925. An oscillator (at 772 kHz) and a frequency selective voltmeter are required. No specific minimum values of NEXT are stated here. This is basically an application consideration, and specific values depend on the application. For a more detailed discussion on NEXT considerations, refer to TE&CM Section 950, PCM Carrier for Rural Telephone Systems.

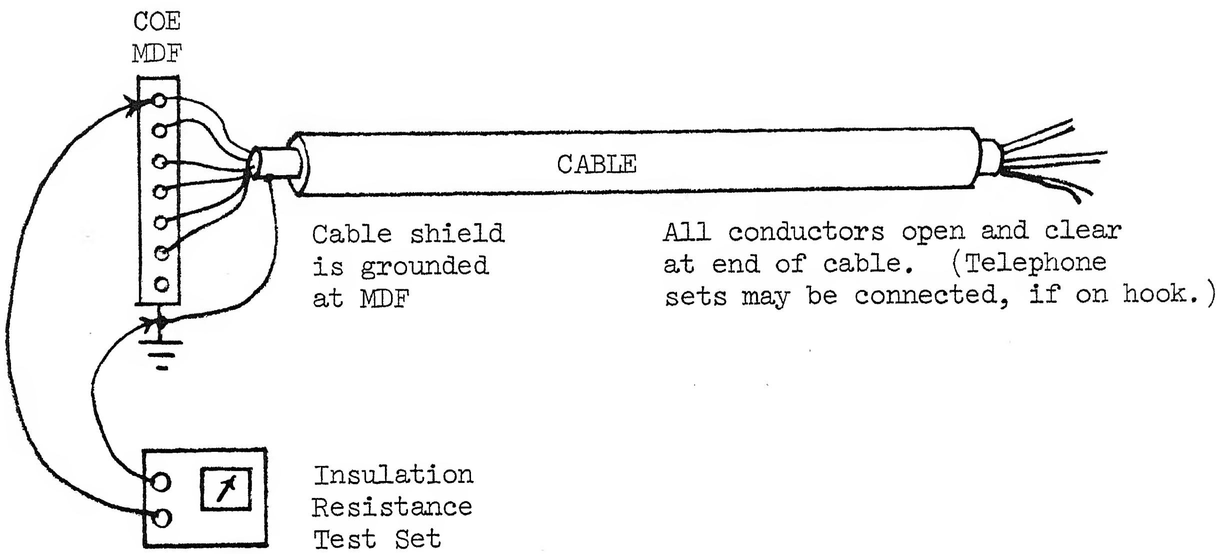
9. CORRECTIONS TO CABLE PLANT

9.1 If cables are found to be marginal or unacceptable under the guidelines provided, do not apply carrier systems until the problem areas are corrected. Tighten ground and bonding connections. Repair broken shields. Replace improperly installed shield bonding connectors, if necessary. Clean up all exposed terminal blocks.

9.2 If moisture is found in sections of cable, this might be corrected using the vapor drying technique described in REA Telephone Operations Manual, Section 1357. Vapor drying is not effective in small cables. The application of carrier on cables that have been "reclaimed" with reclamation compounds is not recommended. Vapor drying restores the cable transmission characteristics; reclamation compounds do not fully restore the cable loss and impedance characteristics. If faulty cable sections cannot be repaired or restored, they must be replaced before carrier is applied.

FIGURE 1

INSULATION RESISTANCE MEASUREMENTS



Notes:

1. The insulation resistance test set output voltage should not exceed 400 volts to avoid firing central office or station arrestors.

2. Measure many pairs at the central office mainframe (MDF). Measure tip to ground, ring to ground, and tip to ring. If other cable pairs are connected to COE line circuits, they are effectively grounded. If they are not connected to line circuits, all pairs of cables are grounded except the wire or pair being measured.

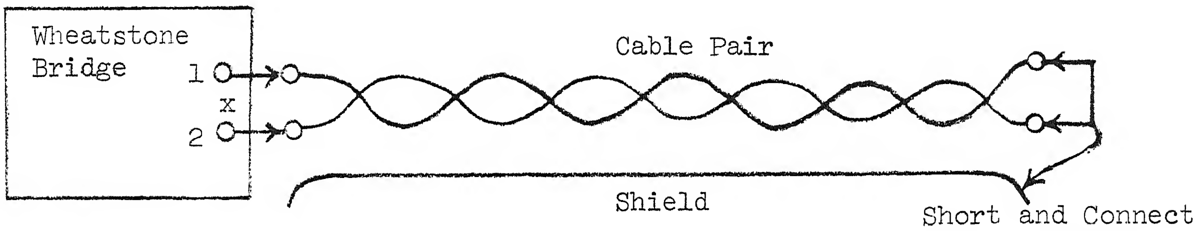
3. Question all measured values of less than 50 megohms. Attempt to find and correct the cause of low insulation resistance.

FIGURE 2

SHIELD RESISTANCE USING WHEATSTONE BRIDGE

Using a wheatstone bridge, measure the loop resistance (R1) of an idle pair between the two pedestals. Record the resistance (R1).

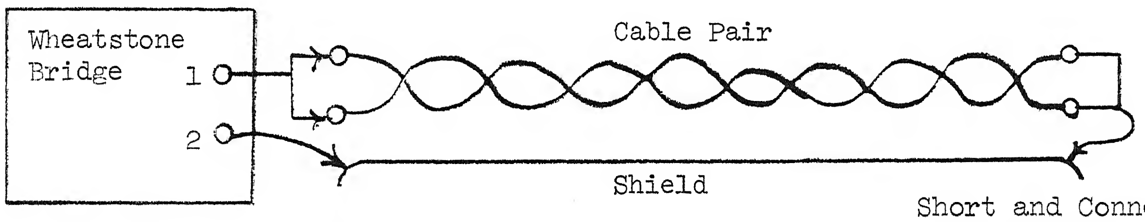
Loop Resistance



R1 = ______

Short tip and ring of the pair at both ends. Connect the end of the pair to the shield. Measure the resistance (R2) and record the value

Loop Resistance



R2 = ______

The shield resistance (Rs) is:

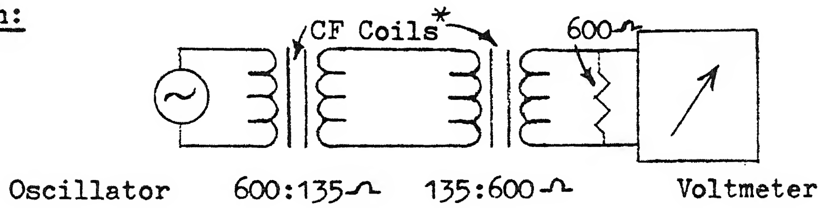
$$Rs = R2 - \frac{R1}{4}$$

If Rs exceeds the calculated shield resistance, there is an open shield. How can the location be pinpointed? There are several fault location instruments available. The success seems to vary with the instrument ---- skill of tester, and type of fault. Use your own experiences to you in this area. Refer to REA Telephone Operation Manual, -s 1356.4 and 1356.6 for additional information on fault location. ---ry 3, 1975 issue of Telephony also contains an article entitled With What - To Find Cable Faults" by A. E. Wilson. The views a variety of fault location instruments and their use.

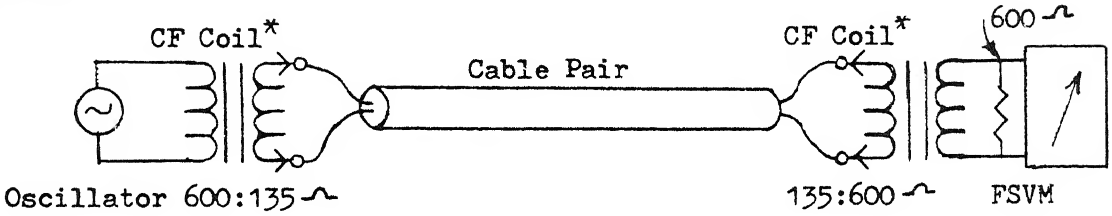
FIGURE 3

CARRIER FREQUENCY INSERTION LOSS MEASUREMENTS ON CABLE FACILITIES

<u>Calibration:</u>



<u>Measurement:</u>



<u>Test Equipment</u>:

Oscillator	=	HP 204C Oscillator or equivalent
Voltmeter	=	HP 403B Voltmeter or equivalent
Frequency Selective Voltmeter (FSVM)	=	Rycom 3126 or equivalent
Carrier Frequency Repeating Coils (CF Coil)*	=	Lynch 2692 or equivalent

* Repeating Coils not needed if oscillator and voltmeter are 135 Ohms, balanced.

<u>Calibration Procedure</u>: Calibrate the oscillator for 0 dBm as shown at each frequency to be measured <u>or</u> calibrate for 0 dBm at one frequency and sweep the oscillator through the measurement frequency range to see that the level does not vary more than ± 0.2 dB.

<u>Measurement Procedure</u>:

1. Connect the calibrated oscillator to one end of the length of cable to be measured and the FSVM to the other end as shown.

2. Record the insertion loss (in dB) of the cable at each specified frequency.

3. The measured insertion loss of the cable should be within ± 10 percent of the calculated loss in dB when the loss is corrected for temperature.

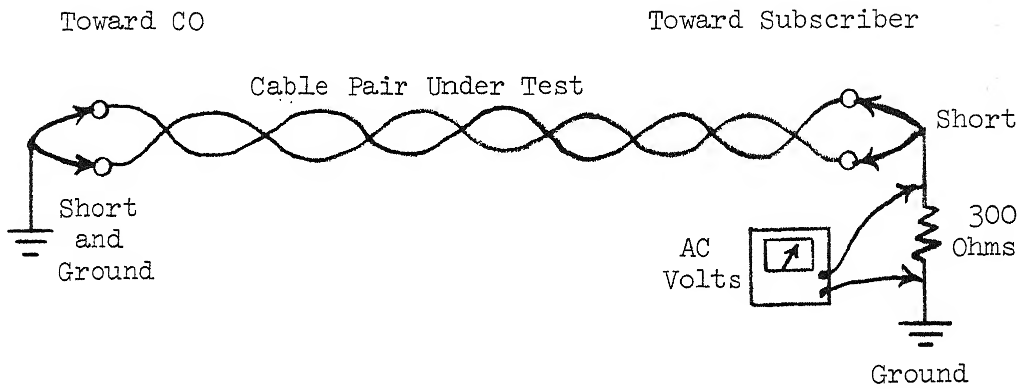
4. Carrier frequency repeating coils having an impedance between 100 and 135 ohms on the cable side are acceptable.

5. Refer to TE&CM 925 for more details on measurement.

FIGURE 4

MEASUREMENT OF AC VOLTAGE ON CABLE PAIR

Using an ac voltmeter, measure the 60 hertz voltage on the cable pair intended for station carrier application. To approximate actual carrier system application, measure in repeater section lengths.



Record the 60 hertz voltage across the 300 ohm resistor on the field side of the cable pair. The cable pair should be shorted and grounded on the central office side.

TABLE 1 - CABLE DATA

NOTE: This is a quick reference for cable data. Refer to TE&CM 406 for more complete transmission facility data.)

A. ATTENUATION (dB/kF) Solid PIC Insulation

Freq. (kHz)	Filled (Gauge)				Air Core (Gauge)			
	19	22	24	26	19	22	24	26
112	0.99	1.52	2.15	3.18	1.15	1.69	2.38	3.43
140	1.11	1.63	2.25	3.30	1.29	1.83	2.51	3.58
180	1.26	1.80	2.41	3.45	1.48	2.05	2.72	3.78
260	1.52	2.15	2.75	3.75	1.82	2.48	3.17	4.17
500	2.12	3.00	3.75	4.77	2.57	3.52	4.44	5.46
772	2.61	3.76	4.70	5.90	3.19	4.47	5.64	6.87

NOTE: Attenuation data shown at 68°F; for other temperatures, attenuation increases or decreases approximately 1 percent for each 7°F increase or decrease in temperature.

B. DC RESISTANCE (Ohms/kF)

Gauge	19	22	24	26
Ohms/kF	16.10	32.39	51.89	83.33

NOTE: Resistance is shown at 68°F; for other temperatures, resistance increases or decreases approximately 1 percent for each 5°F increase or decrease in temperature.

C. SHIELD RESISTANCE (Ohms/kF)

The following data can be used to determine the approximate resistance of cable shields; the actual resistance can vary somewhat. For 5 mil. copper, 8 mil. aluminum or 6 mil. copper-steel shields, the resistance is approximately 0.75 ohms per kilofoot for a 1-inch diameter cable.

CABLE (Pairs & Gauge)	Diameter (inches)	OHMS PER KILOFOOT				
		5 mil. Copper	8 mil. Alumi-num	6 mil. C/S	10 mil. Copper	5 mil. Bronze
200-24	1.32	0.48	0.51	0.57	0.22	
100-24	0.99	0.64	0.68	0.76	0.30	
50-24	0.75	0.84	0.90	1.01	0.40	
25-22	0.72	0.90	0.93	1.05	0.41	
12-22	0.57	1.11	1.18	1.33	0.52	
6-19	0.56	1.13	1.20	1.35	0.53	2.22

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